DESIGN AND ERECTION OF INCHEON BRIDGE

Man-Geun, Yun, Ph.D., PE
Executive, Vice President,
Samsung C&T Corporation
mgy.52@samsung.com

Hyun-Yang, Shin, Ph.D., S.E.
Bridge Division,
Samsung C&T Corporation
shynis@samsung.com

Jai-Beom, Shim , PE
Executive Director,
Samsung C&T Corporation
shim123@samsung.com

Hiroshi, Tanaka, Dr.Eng., PE
Technical Consultant,
Bridge Division,
Samsung C&T Corporation
Tanaka.hiroshi@samsung.com

Hwa-Soo, Kim
Executive Director,
Incheon Bridge Site PM,
Samsung C&T Corporation
hs01kim@samsung.com

Jong-Ho, Yang
Incheon Bridge Design Team,
Samsung C&T Corporation
yjhgen@samsung.com

Abstract: *This paper presents the comprehensive design and erection technologies of Incheon Bridge that is characterized by using design-build fast-track method. AASHTO LRFD bridge design code was used for design. Automated prefabrication was performed at factory for tight QA/QC and erection was fully automated.*

Keywords: Incheon, cable stayed bridge, design build, fast track, dimple cable, friction damper, and geometry control

1 INTRODUCTION

1.1 Outline and major features

This project is 12 km-long marine bridge project. It connects the Youngjong Island (West), where Incheon International Airport is located, to the Songdo Free Economic Zone (East) in Incheon City. The work is funded as the SOC (social overhead capital) bridge project which a foreign concessionaire invested for the first time in Korea. This landmark bridge is expected to be a catalyst to lead Korean economy in Asian Trade. The government expects the traffic volume will grow to 90,000 vehicles per day in 30 years. The project concessionaire is IBC (Incheon Bridge Corporation) comprising Incheon

City and AMEC (British company). Samsung Corporation is the D&C contractor representing the joint venture of seven construction companies (Samsung, Daelim, Daewoo, GS, Hanjin, Kumho, and Hanwha). The project cost is 1.3 billion US dollars and total construction period is 52 months. The bridge will be operated by IBC for 30 years, then transfer to government. Unlike many past projects in Korea, the fixed-lump-sum-price for contract method was applied to Incheon Bridge project. The design-build fast-track method was applied for the first time in Korea. Design using AASHTO LRFD design code differs from the previous application of allowable-stress design-code. Incheon Bridge project consists of the three types of bridges such as the 1.48km-long cable-stayed bridge (CSB), the approach-bridge and viaduct including the ship impact protection and toll plaza (Figure 1). CSB having the 800m-long main span is the world 5th longest bridge. The bridge ranks 7th longest bridge (21.27km in total) in the world [1] [2].

Figure 1: Whole location and scale of Incheon Bridge and its main span (CSB)

1.2 Bridge route and natural condition

The curved bridge route was selected because the government requested the bridge to be located 3 km south of Incheon harbor for safer approach of vessels passing under the bridge (Figure 2). This bridge is an obstacle from the viewpoint of ship navigation. Therefore, the marine authority asked concessionaire to design the ship impact protection dolphins around the piers to resist against 100,000 DWT design vessel with the 10 knots speed. The tidal difference is about 9m from -4.5m to +4.5m that made construction extremely difficult. Therefore, the major erection by the floating crane was executed considering the safe tidal time around the mean sea level. The water's turbidity is dense and the current speed is 1.7m/sec. Sever weather reports are frequent about 40 times for strong wind, seaway and bad visual distance, and gets 96 days/year of rain. Therefore night time and Sunday work hours were necessary leading to average working day per month of 20 days. In addition, traffic-control of the workboats was needed to avoid accidents with the 200 vessel passage per day to Incheon harbor. These are the reasons why this project applied the prefabrication method at the factory to make most of marine work at minimum level.

Figure 2: Bridge route

1.3 Construction Procedure

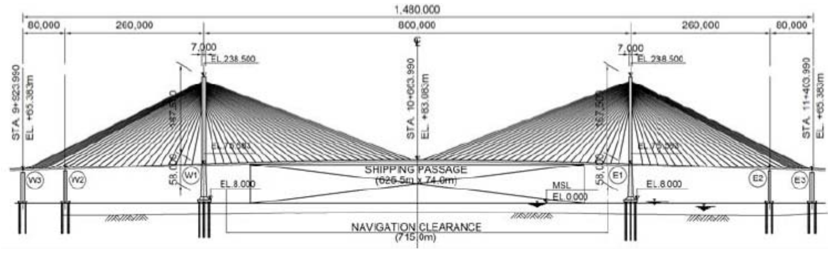

Figure 3: General view of cable-stayed bridge

In case of CSB (Figure 3), in July 2005, the construction has commenced as installing the working platform for the foundation. The 24 concrete piles of 3m diameter were casted in placed down to the bearing layer of hard rock after the steel pipe driving and drilling inside. In November 2005, the PC house prefabricated at the factory was transported and installed on top of the piles. And then, the re-bar and concrete works for the pile cap and pedestal were carried out. In June 2006, the automatic climbing form for the pylon was installed. Then, through the temporary strut & tie works as well as the erection of pre-cast cross beam, the 238m-high pylon was completed successfully in February 2008. After that, the prefabricated large block side span girders were erected over the temporary bents and the center span girder cantilevering with the cable was completed in December 2008. In a similar way, the substructure of approach-bridge and viaduct at both sides of CSB was completed. The superstructure was prefabricated at the factory and erected by equipment for step by step completion by the end of February 2009, too. In brief, this project is characterized by prefabrication, pre-cast, large block and automation by equipment. The ship impact protections were also installed. The ancillary works like bridge pavement, cable damper and inspection access facilities lastly finished for completion in October 2009.

2 DESIGN

2.1 Design criteria

The project contract documents such as PPR (Project Performance Requirement) and CSR (Concessionaire Supplementary Requirement) specified AASHTO LRFD bridge specification (Limit state design principle) and PTI (Post-Tensioning Institute) recommendation 4th edition for the detail design of stay cable (Figure 4). The vessel navigation clearance is 625.5m by 74m above the mean sea level and the service design life for durability is 100 years. As the major design loads, vehicular load of AASHTO and Korean Bridge Design Code were considered for the greater load combination. The bridges were designed against the critical wind velocity of 72m/sec, the earthquake of 154gal and the ship collision load of 100,000 DWT with 10 knots.

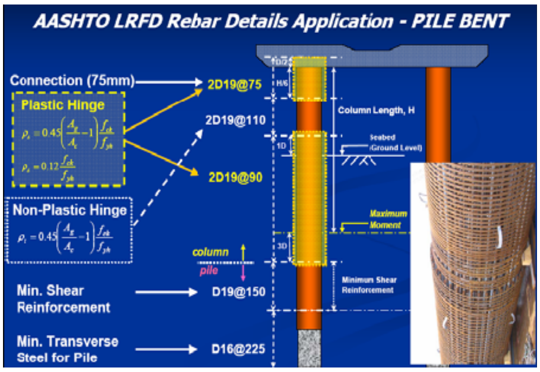

Figure 4: AASHTO LRFD Design application

2.2 Bridge composition

CSB has about a 30m-wide steel box girder with the orthotropic deck, and concrete pylons of 45Mpa. Just beside it, approach-bridge has a 7-span continuous pre-stressed concrete box girder of span length of 145m which is monolithic with the substructure. Viaduct consists of a lot of 5-span continuous pre-stressed concrete box girders of span length of 50m with the bearing on top of the pier which has the pile bent system (Figure 5).

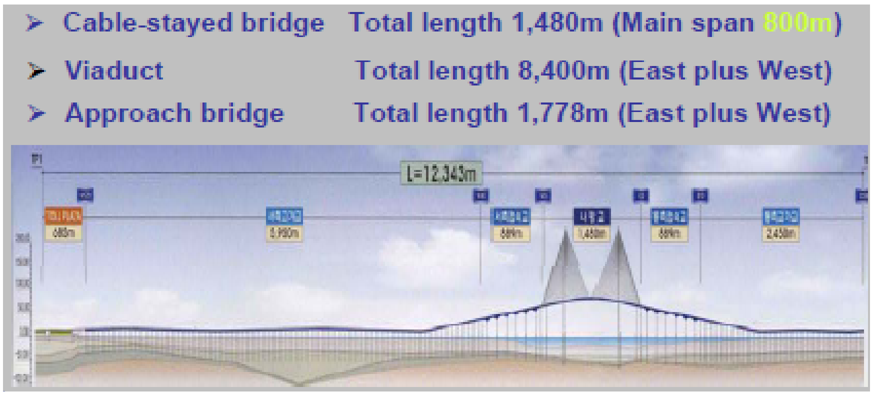

Figure 5: Bridge composition

2.3 Fast track and design assurance system

Fast track method was applied as construction method. At the beginning of project, many tests and investigations like wind tunnel tests and pile load tests were carried out to find out the design parameters accounting for the detail design. Design has been implemented by stages from substructure to superstructure. For example, while designing the foundation of bridges, all facilities for the factory were set and the working platforms were installed around the position of foundations on the sea. To keep the design quality assurance, the design documents had been reviewed and approved by the independent design checker, design & construction supervisor, concessionaire and government design deliberation committee in phases before each design package began to be executed at site (Figure 6).

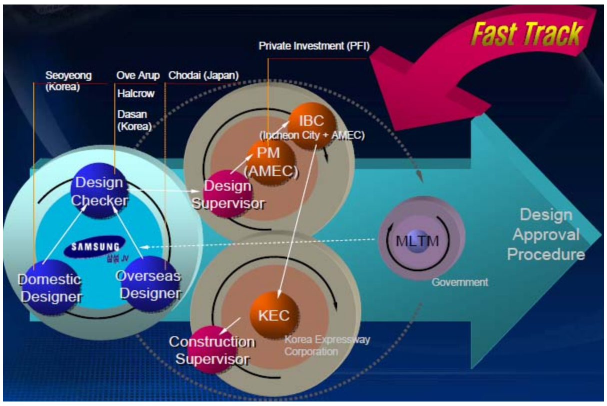

Figure 6: Fast track and design assurance system

2.4 Decision of construction method for efficiency

To save the construction period and to keep the high quality, each 50m-long girder segment of viaduct was prefabricated by FSLM (Full Span Launching Method). In a similar way, for approach bridges, 20m-long large block segment 3 or 4m-long span segment were erected by pre-cast segmental FCM (Free Cantilever Method). Also, 15m-long cable-stayed bridge girder segment was erected step by step by using PWS cable. The prefabricated 25m diameter ship impact protection dolphin was installed around the pile cap at a time. As the design feature of CSB, the steel anchorage for cable at a pylon top was adopted to save the construction time and enhance the erection accuracy. The 2-D and 3-D wind tunnel tests confirmed that the slender girder is stable up to 72m/sec and also flutter will not occur (Figure 7). The penetration depth of 80% thickness of u-rib was kept in welding to the steel deck.

Figure 7: CSB erection and wind tunnel testing

3 TECHNOLOGIES FOR CONSTRUCTION

3.1 Viaduct superstructure and substructure

Viaduct consists of a lot of 5 span continuous pre-stressed concrete box girders over the bearing on top of the pier which has the pile bent system. Its span length is 50m and bridge total length at east and west side is about 8.4km; about 70% of this bridge route. The girder height is constant to 3m and its concrete strength is 45Mpa (Figure 8).

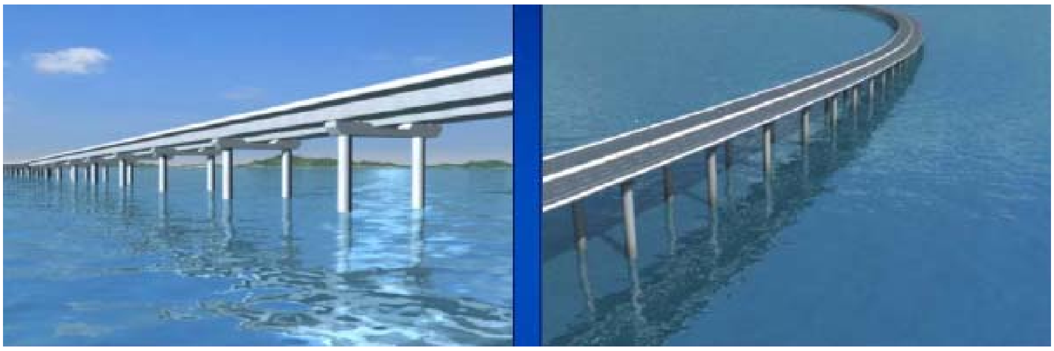

Figure 8: Viaduct bridge/5,950m (West Bridge)/2,450m (East Bridge)

FSLM is based on the pre-cast girder segment production and the launching gantry was applied to the erection. The 50m long and 1,350 ton girder are prefabricated at the factory and transported to the marine site by the overhead crane and barge. After that, it is lifted by the 3,000 ton floating crane and loaded over the carrier to move it to the launching gantry. The 600 ton carrier is a combination of 4 trailers having 20 wheel axes each other. During construction stage, this carrier distributes the self weight plus girder weight of about 2,000 tons well to the up and down line girders already installed. At the position of launching gantry, the transported concrete girder was positioned over the steel-support-bridge and was lifted by the launching gantry for erection. The main reason why this method was applied is to save time and to keep high quality; in addition, it realized the minimum size of factory to store the pre-cast segments. Actually, one girder was produced only in 2 days through the steam curing of 17 hours up to 60 degrees Celsius at the factory and the erection of one girder took only one day at site. The pre-stressing tendons were pre-tensioned in a longitudinal and transverse direction before casting the concrete to save the construction time and cost. The grouting and expensive post-tensioning anchorages were omitted. Then the pre-stressing loss and stress in girder was monitored through the measuring instrument, and confirmed the girder in healthy condition. In substructure, the pile bent type for viaduct, based on AASHTO LRFD bridge design method, was applied first in Korea (Figure 9). The structural safety was verified through the seismic resistance performance and pile nonlinear analysis. In aesthetic viewpoint, the surface of sacrificial steel casing, which is used for concrete pile construction, of pile bent only up to EL. -1.0m was covered by applying the metal thermal spray of zinc and aluminum compound after blasting the surface.

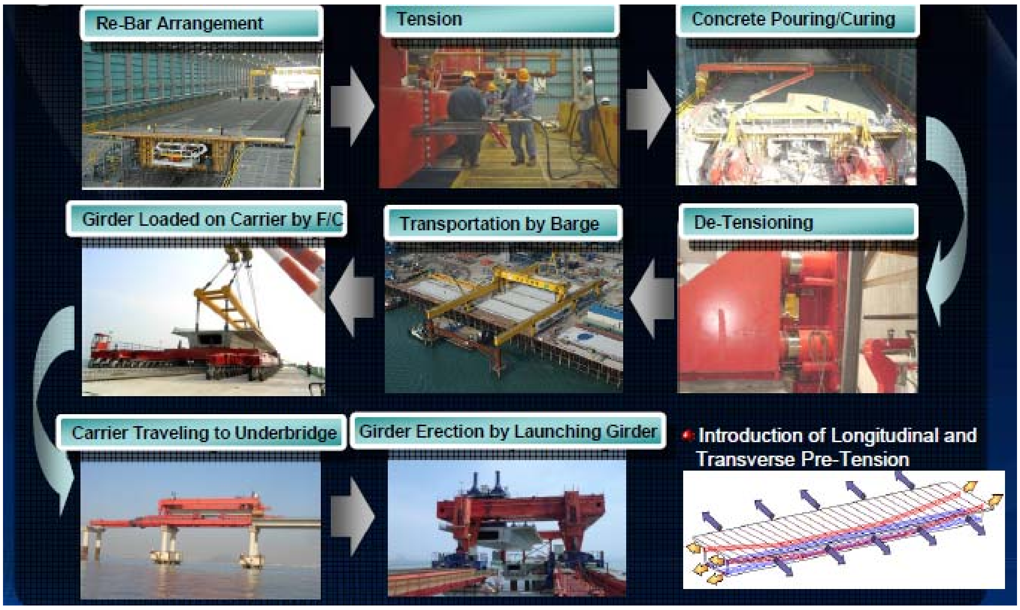

Figure 9: Site fabrication and erection by FSLM

3.2 Approach bridge superstructure

Approach bridge has a 7 span continuous pre-stressed concrete box girder which is monolithic with substructure. Its span length is 145m and bridge length at east and west side is about 890m respectively. The girder height gradually changes 8.5m at pier to 3m at mid span and its concrete strength is 45Mpa (Figure 10).

Figure 10: Approach bridge/889m (West Bridge)/889m (East Bridge)

The pre-cast segmental construction method based on the short line production was applied. The 20m long and 1,500 ton large pier segments over the pier were prefabricated at the factory and then erected by the 3,000 ton floating crane. The 3 or 4m long and maximum 150 ton small span segments were erected by the derrick crane over the deck through the free cantilever method. To fabricate the pier head block, in other words, large pier segment with 50cm thickness and 65 ton match cast block, which would be installed later between the pier and pier head block was produced beforehand. Then, this match cast block was used as a formwork for the pier head block which was placed up to the lower part of web first and placed again up to the slab secondly. The small span segments were fabricated in general short line method and being erected within a vertical tolerance of 150mm, which is 1/1,000 of span length. First, the base span segment to the pier head block was connected by placing the 150mm thick cast in place concrete. The accurate erection is very important for geometry control because all the next segments are match cast based on this segment. Finally, the 2.7m long pre-cast key segment was fabricated and installed by lifting equipment manufactured specially over the leveling beam. Finally cast in situ concrete at the remaining 0.3m space for closure was installed (Figure 11).

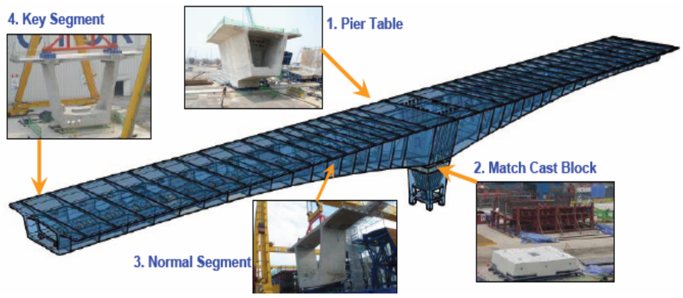

Figure 11: Erection sequence of approach bridge

3.3 Pylon

The pylon of CSB is 238.5m high and inverted Y shaped concrete structure. It consists of 4 parts; lower part, cross beam one, middle and upper cable anchorage one and their concrete strength is 45Mpa [3].

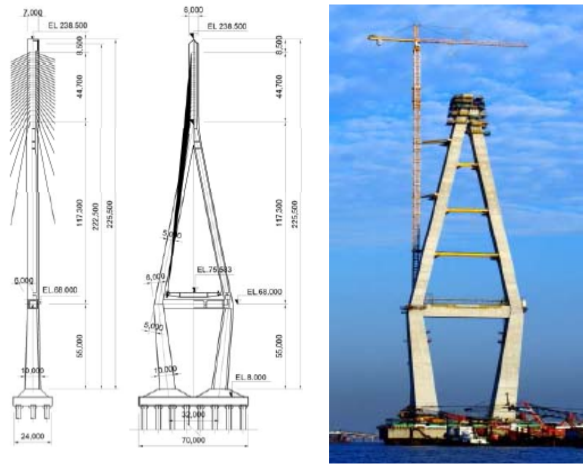

Figure 12: Dimension and erection scene of pylon

For construction, the pylon was divided into 57 lots with 4m height and the automatic climbing form was applied because of the variation of pylon section and its slope considering influence of wind force. Lower part lot was constructed at a rate of 11 days and middle part was only 4 days. The cross beam is prefabricated at the factory to save the construction time of 3 months and erected by floating crane. The in situ concrete was casted to connect the lower part and cross beam, and the pre-stressing tension was post tensioned. The steel anchorage was installed inside the upper part to save the construction time and improve construction quality and accuracy. It took 24 months to complete the pylon. The design required the vertical accuracy of 1/2,000 and design vertical camber was calculated as about 185mm which considered the elastic shortening, creep and shrinkage of concrete. The temperature and shape were ensured each lot as well as some specific position like the base of lower part, cross beam and connection part of 2 pylon legs, and compared with the design value during construction. The camber was reflected at the just below of cross beam, connection part of 2 pylon legs and upper anchorage part. Approximately 200 ton axial force at the temporary tie of lower part and 3 each temporary strut of middle part was applied to reduce the pylon bending moment and controls the displacement of pylon during construction (Figure 12). Up to the 5th lot from the pylon base, the pump car from marine concrete batch plant was used. For higher position up to upper anchorage part, the high pressure piping placing method was applied to save construction time. Through the review, the high pressure pumps having more than 165bar pressure and concrete placement capacity of 59m^3per hour was used. It was possible to place the concrete within 3 to 4 hours about each lot. Through geometry control, the pylon was constructed with the accuracy of 1/14,000 more than the design value. At the pylon top, the construction error in the bridge axis direction was 20mm after completion (Figure 13).

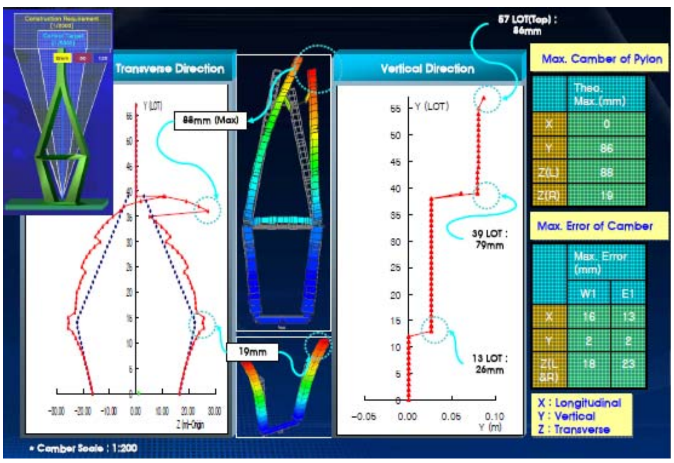

Figure 13: Pylon geometry control of casting curve

3.4 Cable and damper

CSB applies fan-type system with 26 sets of cables in two planes using PWS (Parallel Wire Strand); each cable consists of a bundle of 109 to 301 with 7mm diameter parallel wires and is covered with HDPE having the dimple on its surface (Figure 14). This type of cable is selected for the easier construction at the marine site even though it requires the more and heavier equipment over the deck. The cable is fabricated at the factory in China and transported as the type of roll, and erected at a time. The maximum cable is about 420m long and weighs about 50 tons and carries the maximum load factored tension of 1,030 ton. The cable reel from the supplier's factory is lifted by crane over steel deck. The cable reel supported on the drum is unreeled and evolved by equipment and winch. By using tower crane, the dead anchorage was inserted to guide pipe at pylon top and the live anchorage was inserted to guide pipe at girder side for tensioning by center hole jack. For the cable damping, the dimpled cable covering and friction damper plus buffer system, which is maintained easily, are adopted to ensure a minimum damping ratio of 0.5 % [4].

Figure 14: Cable with dimple surface and its disc-type friction damper

3.5 Girder and geometry control of CSB

For the side span girder-installation, the prefabricated 4 span large blocks weigh about 2,700 tons at a maximum were erected over about 90m high temporary bents by the lifting of 3,000 ton floating crane. Then for the center span girder-installation, the prefabricated 15m long span blocks weigh about 300 tons were erected by the lifting of derrick crane over the deck, and connected with the already erected blocks step by step through the welding and bolting works (Figure 15). After that, the cables are installed and then tensioned by the 800 ton center hole jack, and the control of cable tension and girder geometry were carried out to get the design value [5].

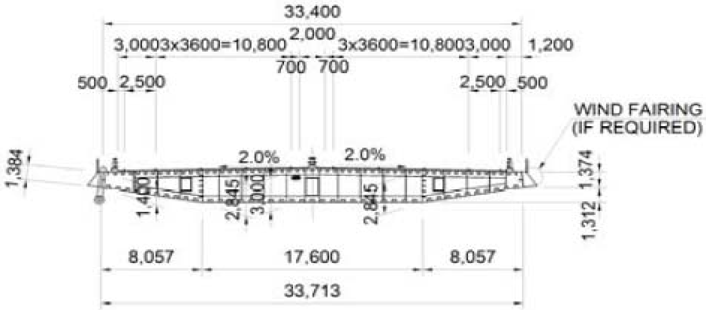

Figure 15: Girder configuration

The allowable tolerance of girder level is within plus-minus 200mm at the center of main span for this project. The optimum geometry control system was established. The configuration, weight, stiffness of

bridge and the position of equipment were modeled previously and the variation of cable tension and girder geometry due to the variation of equipment movement, temperature and cable length were predicted. The monitoring of the bridge during construction was excused by surveying girder levels and measuring cable tension forces. By the newly developed optimum shim analysis, cambers and cable tension forces were controlled properly (Figure 16). As a result of it, superstructure was completed precisely in December 2008 [6].

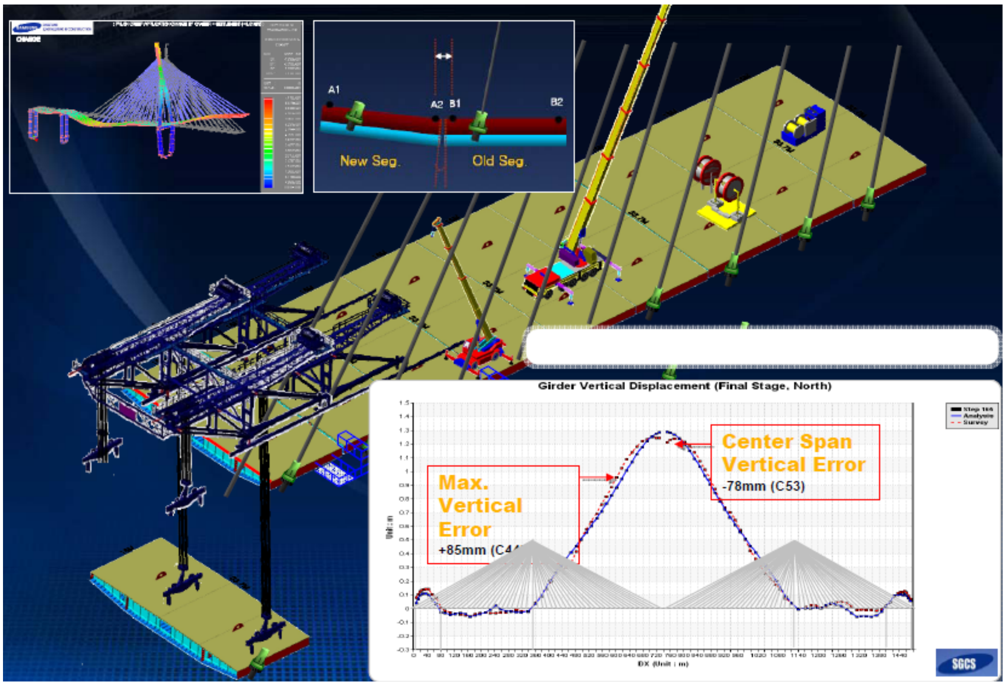

Figure 16: Geometry control of girder and cable

3.6 Maintenance

The humidification facility over inorganic zinc paint for corrosion protection was applied, and many inspection facilities and health monitoring system were designed to help maintenance works. The design service life of this bridge for durability requirement is 100 years. For this, basically, the marine concrete was used to resist against any damage from the sea salty water. The 2 components or 3 components cement, which includes the blast furnace slag powder and fly ash, was used. The water binder ratio of less than 40% was applied. For confirming the marine environmental condition, the amount of salt content over the Incheon sea water was investigated. And, the testing was performed to find out the chlorine ion diffusion coefficient into concrete specimen. From analysis, the different proper net concrete cover to rebar in each concrete section was applied according to each concrete member and its location on sea. The cover was around 110 to 130mm for concrete pile, 75 to 115mm for pier and 70mm for pylon, 45 to 50mm for concrete girder. Actual specimen exposure testing to sea water to verify the durability is being carried out additionally although the calculation above would be proper on the basis of experience.

3.7 Ship impact protection (SIP)

This project provides 38 cylindrical ship impact protection dolphins around the foundation of pylon, intermediate pier and end pier of cable-stayed bridge, and 1st pier of approach bridge to protect bridge from colliding with the vessel. The design vessel is 100,000 DWT with the speed of 10 knots at the navigation clearance of 625.5m by 74m. Each dolphin has the 25m or 20m diameter, and consists of the 12.7mm thick thin straight type sheet piles and crushed stone filled inside piles. The height of dolphin is about 38m including the embed length of 13m below sea bed level. About 160 sheet piles were pre-

fabricated around the template through the tag welding after the template was installed at the factory. It takes 12 days to complete this work including spraying the corrosion protection paint. After fabrication, this 1000 ton template with sheet piles were lifted and transported by 3,000 ton floating crane. The template at marine site was fixed to the ground by driving the 8 pin piles. And then 3 sheet piles were driven to the designed depth by vibration hammer at the same time. After that, the upper and middle part of templates was removed and the lower part was moved to the upper position. After that, works like a filling of stone, pulling out of pin pile, installing and placing of concrete cap was executed. The required sheet pile amounts to 16,000 tons and the crushed stone amounts to 460,000 tons (Figure 17).

Figure 17: Prefabrication and erection of SIP

REFERENCES

[1] SHIN, H.Y. NAKAMURA, H. et.al. 2006. Design of Incheon Bridge in Republic of Korea – Planning and Design of Cable – stayed Bridge on Design-build Procedure –, *Bridge and Foundation, May 2006, Kensetsu Tosho*

[2] YANG, J.H. YUN, M.G. 2007. Incheon Bridge project outline. *4th International Conference on Bridge Maintenance, Safety and Management*

[3] SHIN, H.Y. YU, W.J. et.al. 2006. Cable-stayed Bridge Design of Incheon Bridge in Republic of Korea – Design of Pylons and Anchor Piers – *Bridge and Foundation, October 2006, Kensetsu Tosho*

[4] YANG, J.H. AHN, S.S. KIM, H.K. 2006. Design of cable dampers and buffers in Incheon Cable-stayed Bridge. *7th Seventh International Symposium on Cable Dynamics*

[5] SHIN, H.Y. YANG, J.H et.al. 2008. Cable-stayed Bridge Design of Incheon Bridge in Republic of Korea – Design of Girder and Stay Cable – *Bridge and Foundation, February 2008, Kensetsu Tosho*

[6] IM, D.K. YOO, J.K. KIM, C.H. TANAKA, H. KIM, H.S. 2009. Development and application of integrated geometry control system in Incheon cable stayed bridge, *International Commemorative Symposium for the Incheon Bridge, Korea*